

The Effects of Colour and Light on Health: Trans-disciplinary Research Results

A Latrobe Fellowship research team explores the value of a collaborative approach to evidence-based design through a pilot study of the effect of colour and lighting on patient well-being.

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The College of Fellows of the American Institute of Architects (AIA) awarded the 2005-2007 Latrobe Fellowship to a consortium formed by Chong Partners Architecture, Kaiser Foundation Health Plan and the University of California, Berkeley, in order to further research of relevance to architecture within healthcare settings.

The premise of the research was to investigate the practice of evidence-based design (EBD), a term used by many designers, despite the lack of research about the human response to design that can be used to inform design decisions.

The Latrobe research team hypothesised that a collaborative approach would benefit EBD by integrating the architect's design experience, the academic researcher's rigorous

methodologies and the client's understanding of institutional decision-making. In addition, the team proposed that a transdisciplinary approach, using physiological, behavioural and economic measures, would increase the quality and applicability of research findings. The team committed to test this model through a pilot study of the affects of colour and lighting on patient wellness outcomes.

There were therefore two major goals of the research:

- To create knowledge that could be applied in hospital and other environments;
- To assess the approach itself in terms of its value as a model for research to be used in EBD.

The research plan developed included the following initiatives:

- A review of design and biomedical literature about colour; lighting and health outcomes (to inform the pilot study);
- A literature review on evidence-based practice (to add context to the research);

- Creation of a database that integrates patient medical records, facility (CAFM) data (including room design attributes), and patient surveys;

- A laboratory experiment, built on circadian rhythm research, that investigates the effects of lighting on psychological and physiological measures known to relate to health outcomes;

- Design interpretation of the various findings; and

- Disciplined assessment of the research model.

The database development is being led by Kaiser Permanente (KP) and is expected to include 100,000 patient stays. It will be used to assess the effects of design interventions on patient medical conditions, for example, healing and patient satisfaction with their hospital experience. It will also be used to correlate existing room design attributes with medical and satisfaction data. The laboratory experiments, referred to here, assess the influence of lighting on human responses and the implications on design interpretations.

Evidence-based practice

Evidence-based practice may be seen as consistent with tendencies in our information-based society toward the production of knowledge in a transdisciplinary, socially-relevant context. Its roots are widely acknowledged to be in the healthcare industry, where a strategy of standardisation known as 'evidence-based medicine', has emerged over the past two decades¹. A core principle of evidence-based medicine is "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients."² In evidence-based medicine, the skills and experience of the healthcare provider; the needs and concerns of the patient; and evidence grounded in rigorous scientific methodology stand as the three foundational elements of a model for decision-making.

This model has since migrated to other disciplines, including education, social work, information technology, environmental

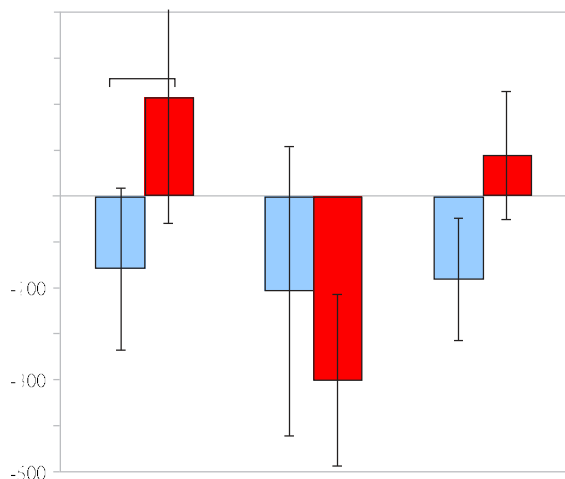


Concord lighting in the chapel at St Lukes Hospital, London:
The influence of light on health is relevant to all architectural environments

Edelstein et al. (2007)
 The Affects of Colour and Light on Health:
 Trans-Disciplinary Research Results.

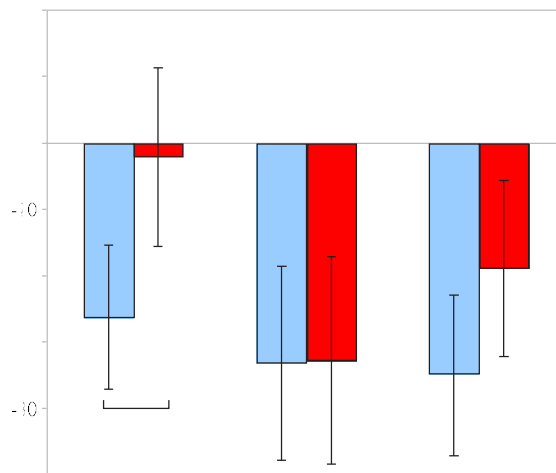
HF reactivity scores

Figure 1



IBI reactivity scores

Figure 2



management and architecture. While the extent of acceptance and implementation of evidence-based practice varies widely, a common motivation is the observation that current practices in these disciplines are unsystematic, overly reliant upon intuition, prone to undue political influence, or simply ill-suited to enhancing outcomes. That said, the underlying objective of evidence-based practice is the enhancement of outcomes by augmenting practitioner experience and skills with valid and reliable data.

What constitutes evidence and what are appropriate standards? The literature search conducted by the Latrobe team revealed that definitions of evidence and appropriate research standards vary across and within disciplines. A proponent for evidence-based practice in information technology, for instance, suggests balancing multiple types of evidence – tangible, testimonial, equivocal, missing and accepted facts – to construct arguments for decision-making and action³. By contrast, proponents of evidence-based practice in education place a specific emphasis on “rigorous, systematic, and objective methods” to generate evidence from randomised experiments⁴.

The Coalition for Evidence-based Policy, in

a user guide prepared for the US Department of Education, defines ‘strong’ evidence as well-designed and implemented randomised controlled trials held in two or more school settings⁵. In another approach, the definitions of evidence and rigour in librarianship move along a continuum from quantitative to qualitative methods subject to the nature and relevance of the research project⁶.

This variability in the definition of evidence is one challenge to the implementation of evidence-based practice. Other challenges identified by the Latrobe team in its literature search include lack of endorsement by researchers and/or practitioners in terms of applicability of the data in actual design decision-making; confidence that the research methodology used was well-designed; concerns about the role of professional judgement and experience; and fear that the architect’s professional experience and judgement will be undervalued.

Challenges in executing an evidence-based approach include: the acquisition of expertise and resources to assess the value of the evidence; transparency of methodology; access repositories for the collection; assessment and dissemination of evidence; practitioner resistance to change; and variable

incentives for evidence-based practice.

The effort to infuse scientific principles into practice has historically characterised the rise and formation of many professions. The architectural profession has not been an exception to this pattern. Recent interest in linking scientific research to the design of the built environment dates to the late 1960s, exemplified by the environmental design movement. However, despite extensive research on the built environment, this material has for a variety of reasons failed to permeate professional practice, leaving architects reliant upon individual experience, intuition and readily available information rather than rigorously-formulated research.

There are indications of a shift toward the application of research and evidence-based practice in architecture, most often referred to as evidence-based design, though the focus thus far has been on the design of healthcare facilities. This attention to correlating the physical environment with patient outcomes, staff satisfaction and performance may be seen as a logical extension to the widespread acceptance of evidence-based medicine.

The influence of light

The Latrobe research team considered many

environmental factors thought to influence human outcomes, including colour, light, location and sound. Literature reviews provided the basis for focusing laboratory experiments on the exploration of the influence of light on health, which has an established research base of relevance to design.

The spectrum of light

Historically, significant attention has been given to the influence of colour on mood, function and its potential impact on healing. A recent review of 3,000 papers by Tofle *et al*⁷ found that “colour-mood associations exist, but that there is no evidence to suggest a one-to-one relationship between colour and emotion”. They concluded that there were “no direct linkages between colour and health outcomes, with insufficient evidence in the literature to imply causal relationships between colour and inherent emotional triggers”.

Re-examination of these findings in terms of brightness and contrast would be more consistent with visual scientists' concepts of colour, and might lead to further understanding about colour perception and preference. Indeed, Tofle *et al*⁷ concluded that brightness and contrast are more strongly related to colour perception than hue itself. Further, it should be noted that the internal state and conditions of each individual tested should be considered.

Medical or ophthalmic status is as important to colour perception, as are cultural and social factors. Methodological comparisons are also important in critical analysis and comparison of the existing body of literature. The conditions under which colour samples were tested varied widely across the studies reviewed. Responses to colour were tested with a range of conditions, from full-scale rooms to small pieces of mosaic tiles. Most studies used small sample sizes with insufficient power for statistical analyses. Finally, the perception of colour is directly related to the reflective and absorptive qualities of the surrounding environment, and the length of time observing the colour.

Chronobiology and rhythms

In contrast, a wealth of empirical research from the field of chronobiology demonstrates the influence of light on behavioural and physiological responses⁸. Solar cycles link daily (circadian) and annual (circannual) rhythms in almost all animals,

including humans. Many biological processes have diurnal patterns, such as cardiac, immune, endocrine, cellular regeneration and brain processes including learning⁹.

Behavioural patterns are similarly related including sleep, activity, feeding and mating. Short-term absence of diurnal lighting has been associated with altered levels of fatigue, disorientation and sleep. Longer-term absence of natural diurnal stimuli has been associated with seasonal affective disorders, depression and psychiatric disorders¹⁰. Patients, visitors and medical staff report the positive experience derived from light, as well as the detrimental disorientation and influence on cognitive function that occurs in the absence of natural lighting patterns^{11,12,13}.

Circadian cycles can be modulated by a variety of external cues, but light is the primary variable that aligns (or entrains) humans to diurnal and nocturnal rhythms. Although decades of research have examined the influence of electrical lighting on circadian entrainment, it was not until 2001 that a new class of cells was discovered in the retina of the eye, thought to be ‘circadian’ rather than visual receptors. This discovery renewed research that explored the spectrum, intensity and duration of light that influences biological responses.

Numerous studies have led to the development of ‘dose response curves’ to electrical light that reveal peak sensitivity in the blue wavelength (approximately 420-440nm) for modulations of melatonin suppression that regulates sleepiness. Bright white light has also been demonstrated to be effective in modulating mood, sleep and activity cycles¹⁴.

The range of spectra that influence the multiple circadian systems is yet to be explored. Complexities exist such that when a singular (monochromatic) light source is presented along with other (polychromatic) light, interaction effects occur, and a spectrum may become less effective at stimulating circadian responses than when presented alone. Thus, Figueiro *et al*¹⁵ demonstrated that melatonin suppression was influenced by polychromatic light, even when the irradiance in the short wavelength (436nm) was equal to monochromatic light of the same wavelength.

Lighting and health

In addition to the spectrum of light, research

demonstrates the importance of light intensity. It has been suggested that typical interior light levels are barely sufficient to stimulate circadian responses, and that the constant, dim, retinal illumination typical in many facilities and urban environments may be insufficient to stimulate circadian responses, leading to significant disruption of biological rhythms and sleep/activity cycles¹⁶.

Recent epidemiological studies suggest that increased cancer rates in night nurses may be related to the lack of light-dark cycles and the almost constant light exposure that they experience at work and at home^{17,18,19}. Studies that demonstrate the relationship between immune function, sleep and healing support the value of further research into lighting and health.

Many studies show that stress also changes rhythmically with diurnal modulation, modulating cardiac and neuroendocrine responses, which are likely to be responsible for the higher levels of cardiovascular disease found in chronically stressed individuals²⁰. Further, cardiovascular function is an underlying mechanism associated with attention and memory.

Thus Porges and Raskin²¹ demonstrated that heart rate was significantly modulated during sustained attention. With the increased interest in the role that stress plays in the development of cardiovascular disease, the influence of built features in architectural environments may have direct relevance to health, performance and well-being. Accordingly, Thayer and colleagues recently demonstrated that physical features of workplace environments, including electrical and day lighting changes, were associated with modulation of day/night differences in cardiac responses, an important indicator of stress and health risk²².

The Latrobe Experiment

The need for additional research that defines the relationship between lighting and health remains – and it formed the basis for design of the Latrobe Experiment. A multi-centre study was conducted, utilising an empirical approach to investigate the physiological and psychological responses to controlled light conditions in both morning and night conditions. The Latrobe study sought to determine the influence of brief ‘light showers’ presented during the day. The objective of the study was to assess transient alerting and

activating effects of light that might be used for modulating psycho-physiological responses inside of built environments. The specific objective of the study at the Department of Psychology, Ohio State University, was to consider the influence of light on heart rate variability, an important indicator of health risk and stress level²³.

A parallel study was conducted at the Swartz Center for Computational Neuroscience at the University of California San Diego to assess the influence of the same lighting protocol on cognitive responses measured via electroencephalography (EEG) and independent component analysis of the brain waves²⁴. Initial results from the EEG study indicated an increased response in the theta band of brain waves from one subject during red light relative to white light, despite the lack of fatigue; however, additional recordings are required in order to confirm these results²⁵.

Statistically significant differences in heart rate reactivity were observed in bright white light versus red light conditions. Following baseline measures in fluorescent lighting, 14 subjects were exposed to 15-minute periods in darkness followed by light exposure to bright white light with a peak in the blue spectrum, and red light produced by LED panels.

Memory was tested using a 2-back working memory task six minutes after light condition change, while electrocardiography was recorded throughout the experiment. Red light exposure was associated with a significant decrease in heart rate [$p < 0.05$], and a significant increase in high-frequency heart rate reactivity (HF-HRV) (t test, $n = 14$, $p < 0.05$), that was confirmed in analysis of inter-beat-intervals. Consistent with studies that show a relationship between memory and

heart rate, there was a significant decrease in high frequency reactivity [F test quadratic, $n = 14$, $p < .001$] during the working memory task, relative to initial baseline and recovery periods, which did not alter significantly. In contrast, heart rate reactivity did not differ significantly during bright white light exposures, using both F and t-tests²⁶.

Implications

The heart rate variability findings provide important evidence that brief exposure to light, even during the day, may influence cardiac responses. They confirm the influence of short-wavelength blue light that has been intensively studied in relation to melatonin responses, and reveal additional information about the influence of light in the red range. Testing of red light is uncommon, and many researchers have assumed that there is little to no effect of red light on the neuroendocrine or circadian systems. However, Hanifin and colleagues²⁷ found that normal healthy humans exposed to 630 nm and 700 nm elicited small reductions of plasma melatonin levels. These findings are consistent with other studies that reveal the influence of a long-wavelength light on cardiac responses²⁸.

Designing for light and sight

The design implications of the original Latrobe research, in addition to the body of existing studies, could change lighting concepts in healthcare environments. These recent findings suggest that provision for brief light exposure (either solar or electrical) could be used to influence health and possibly cognitive outcomes. For example, red light sources in relatively inactive zones might provide conditions that suit patient



monitoring, without causing disruption from bright light likely to disturb nearby patient or respite zones. Brief exposure to bright light might better serve areas where activation and visibility is required. The use of narrow-band blue light could serve circadian modulation at lower intensities (approximately 30lux).

Since biological systems and disease states have different responses to light, we should not naively assume that a single light condition would serve all diseases, disabilities or the consequence of ageing. Whereas it might appear obvious to provide the same sequence of circadian lighting to all patients, each patient's medical condition and length of stay, let alone their individual circadian and social patterns will dictate their circadian needs. Further, day and night

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Solution providers, such as Concord, are increasingly taking the evidence base into account in their lighting designs

staff have conflicting needs from patients. It is therefore suggested that circadian lighting design incorporate a selection of spectral, intensity and timing patterns defined from the literature, but also include controls to account for individual needs.

The interaction between architectural and electrical sources of light should directly inform design decisions that influence the size, geometry, and layout of rooms and materials. Thus, field studies conducted for the Latrobe project showed that borrowed light at distributed and central nurse stations was limited when patient privacy screens and window coverings were closed. As a result, staff relied on overhead lights that were routinely

switched on during the day and night shift.

This varied greatly from the pre-occupancy site of similar design, which provided both adequate levels of light and a view of diurnal light from nursing station areas. The level of external circadian light is of course reliant on compass orientation, but also showed great differences dependent on the use of materials and distance from the window²⁹.

Value assessment

These design hypotheses must be verified in working healthcare settings, and can be readily tested using the mobile cardiac and mental function tasks demonstrated in the Latrobe study. Manufacturers and researchers are currently exploring the production of lamps that take this evidence-base into account, and ongoing research is being pursued to validate the influence of potential design solutions in operational environments. Using evidence from laboratory and post-occupancy evaluations, a human decision hierarchy can be applied to prioritise design options³⁰. Cost analysis of materials, installation, maintenance and energy use can be factored along with health, satisfaction and performance measures to assign value to each design option.

The ultimate goal

Although further research is required, the pervasive influence of light on many human functions underpins the value of architectural and electrical lighting strategies that support both visual and circadian needs. A greater understanding of the influence of light on health is relevant to all environments where architects play a role, but of most impact in healthcare environments where patients, visitors and staff present the broadest range

of conditions and needs.

The advent of wearable technologies now provides the means to study the influence of a variety of design solutions in functioning healthcare settings without impeding the provision of care. The addition of rigorous findings from both laboratory and on-site studies enhances the range of evidence to be considered in a decision hierarchy that balances safety, security, health, performance, emotional, social and economic needs. The ultimate goal of the evidence-based approach that includes literature reviews, epidemiological studies and laboratory experiments is to assist in development of design strategies that support health, performance, emotional and social needs of all users.

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